Black Carbon: Snow Albedo Reduction and Emissions from Cookstoves

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Co-Investigators and Support

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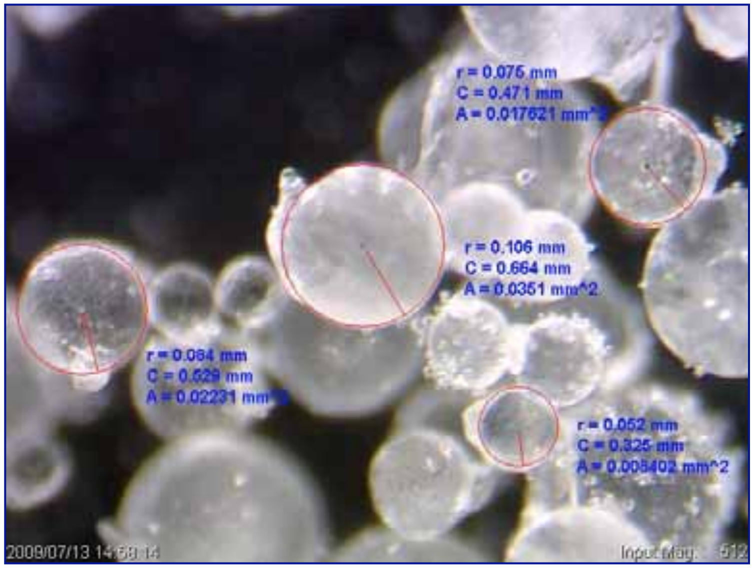
<u>Support:</u> *UC Berkeley (Blum Center, SPS Program), TISS, CEC*

Snow Albedo:

- Odelle Hadley (LBNL)
- Tica Novakov (LBNL)
- Mark Flanner (NCAR)

<u>Support:</u> *Lawrence Postdoctoral Fellowship, DOE*



Black Carbon in Snow Impacts Climate

❖ Sooty snow absorbs more (reflects less) sunlight: positive radiative forcing, regional climate change, global warming

❖ Positive feedback: Soot-induced warming increases snow grain size, which further decreases snow reflectivity and enhances impact of soot

⇨ ppb levels of black carbon in snow contributed to rapid (~1/3 of the) warming of Arctic (**Zender,** *Sci American, 2007*; **Shindell and Faluvegi**, *Nature, 2009*; **Flanner,** *personal comm.*, Sunday)

⇨ Springtime Eurasian snow with black carbon absorbs 2.7 W/m^2 additional solar energy; compare to 1.6 W/m^2 global mean CO_2 forcing (**Flanner et al,** *ACP, 2009)*

⇨ Soot contributes to near worldwide melting of ice (**Hansen and Nazarenko,** *PNAS, 2004*)

Glacier Recession and the Impact of Cookstoves

Consequences of Snow/Ice Melting:

albedo reduction • *global warming* •
seal level rise • *loss of habitat* •
loss of water for consumption, irrigation

Himalayan glaciers are receding faster than elsewhere in the world and many could disappear by 2035 and perhaps sooner

Ganga, Indus, Brahmaputra and other rivers could become seasonal rivers

~1/3 of world's pop. depends on water from glaciers in the Himalayan region

V. Ramanathan, Third-world stove soot is target in climate fight (*NY Times*, 2009)

"It's hard to believe that this is what's melting the glaciers." –

referring to black carbon emitted from cookstoves in rural India

Cookstoves are Major Sources of Black Carbon

Bond, A technology-based global inventory of black and organic carbon emissions from combustion (JGR, 2004)

Residential Biofuel Contribution to Black Carbon Emissions (Cooking/Heating with Wood and Lesser Fuels)	
India	**65%**
China	**30%**
Africa	**65%**
Global	**33%**

V. Ramanathan, Third-world stove soot is target in climate fight (*NY Times*, 2009)

"It's hard to believe that this is what's melting the glaciers." – referring to black carbon emitted from cookstoves in rural India

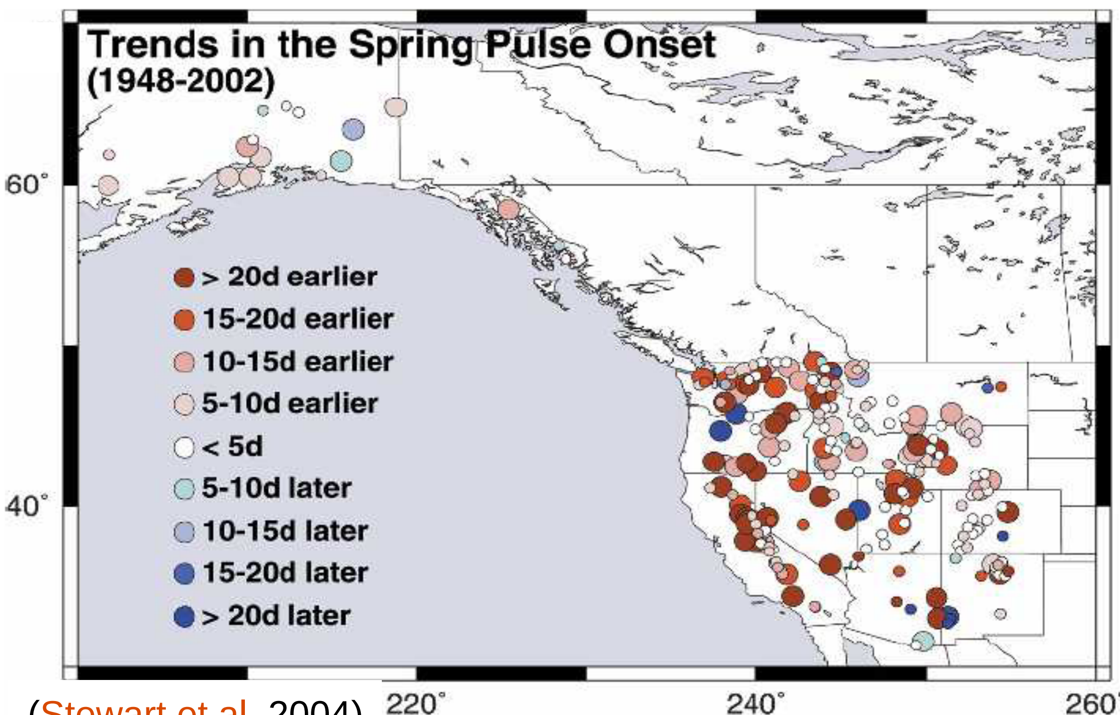
Early Loss of Snow in Western US

- Air pollution over Asia is transported to California

  Hadley et al, Evidence for BC deposition on the Sierra Nevada with implications to regional snow pack retreat and climate change, (*PNAS, 2009, in review*)

  - Black carbon in Sierra Nevada snow is sufficient to perturb snow melt
  - 1/4 to 1/3 of the black carbon in Sierra Nevada may originate in Asia

Onset of spring melt is 10-30 days earlier than 60 yrs ago



(Stewart et al. 2004)

- California relies on Sierra Nevada runoff for water through year
- Early melting, esp if coincident with rain, brings floods, inability to capture runoff in reservoirs

Cookstove Emissions Research

New Project supported by CEC:

Objective: Quantify the emission of light-absorbing black carbon from traditional and technologically improved cooking methods

"Three-Stone Fire"

Berkeley-Darfur Stove

- Heat is directed upwards towards the pot
- Less fuel is needed for same cooking tasks

Designed to Assist Darfur Refugees

Darfur Conflict:

- Sudan civil war created 3 million refugees living in makeshift camps in Darfur
- Women leaving camp to collect wood for cooking are assaulted

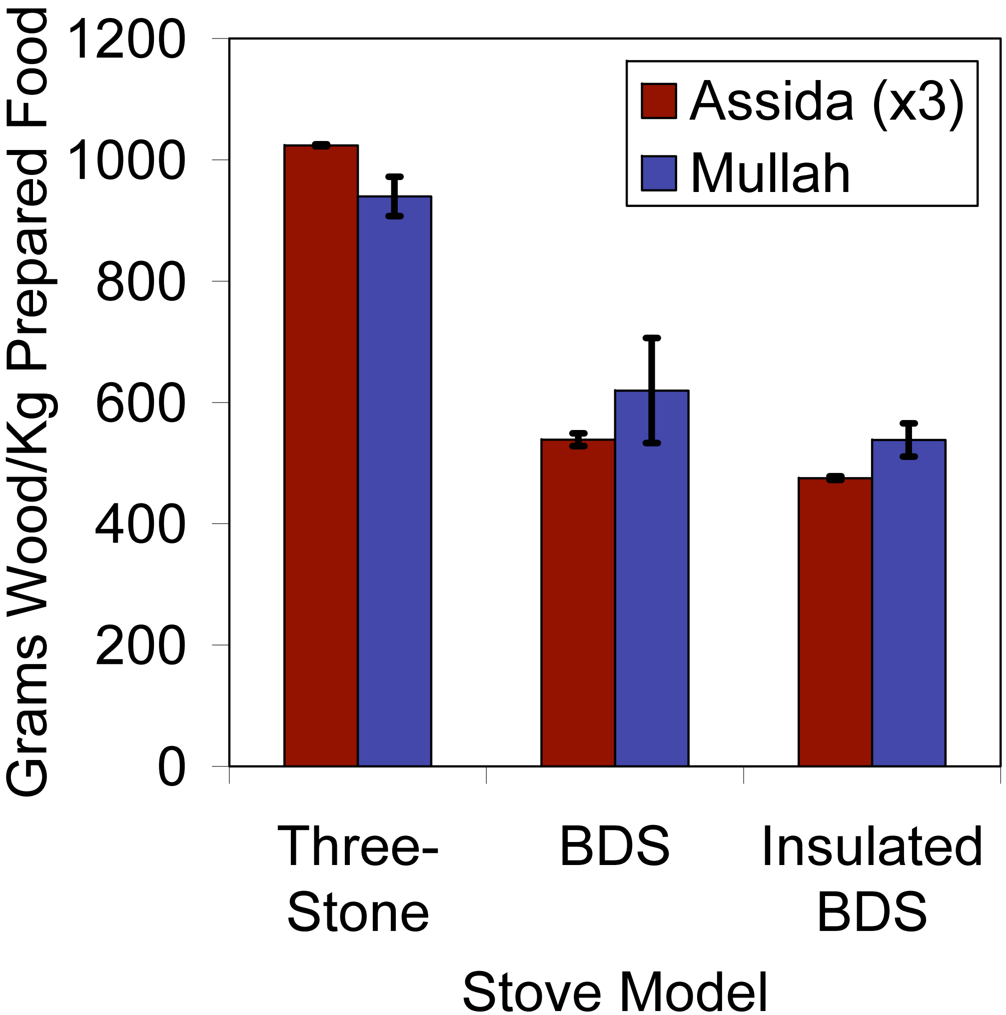
Berkeley-Darfur Stove:

- Inexpensive, culturally acceptable
- Reduce dangerous trips for wood

Ashok Gadgil and Christina Galitsky check ways to modify stoves for Darfur conditions (above). Gadgil gets a local cooking lesson (below).

Berkeley-Darfur Stove (BDS) Efficiency

Efficiency tests with 2-3 m/s breeze on fire



Percent of wood saved compared to Three-Stone Fire for standard cooking tasks		
Stove Model	*Assida (water boiling)*	*Mullah (onion cooking)*
Berkeley-Darfur Stove	47%	34%
Insulated BDS	54%	42%

Cookstove Emissions Characterization

- Compare BC & PM emission factors with few published values
- Add to limited emissions data for cookstoves for global/regional inventories
- Consider potential climate and health impact of technology change

	Pollutant	Instrument	Description
Continuous, 1Hz	Black Carbon	Aethalometer	Light transmission
	Absorption coefficient	Photoacoustic spectrometer	In-situ absorption at 532 nm
	PM2.5	DustTrak	Optical scattering
	CO, CO_2	Infrared Analyzer	Gas analysis
Integrated	PM2.5	Particles collected on filter, Microbalance	
	BC/OC	Thermal-optical analysis of particles on filter	
	Spectral absorption	Spectrometer analysis of particles on filter	

From Black Carbon Emission to Impact on Snow

1. **BC Content in Snow & Ice** → 2. **Albedo Reduction** → 3. **Climate Effects**

1. Models predict black carbon content in snow from emission inventories, atmospheric transport, pollutant deposition

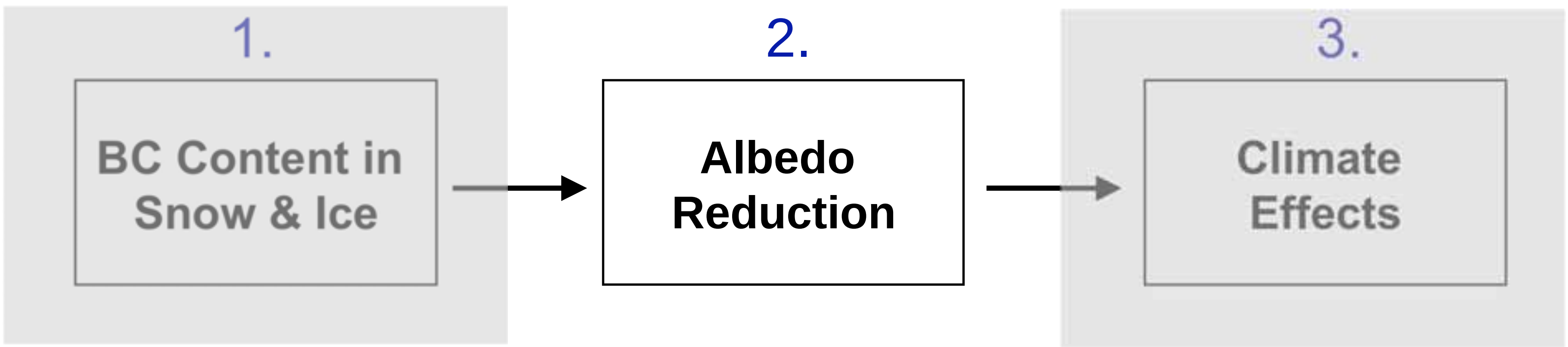
   - some measurements are available to test predictions

2. Estimated from snow-radiation models (e.g., SNICAR)

   - data for model verification is sparse
   - impact of black carbon on snow albedo is masked by other variables (snow grain size, sun angle, underlying surface)

3. Snow-radiation models coupled to climate models

Laboratory Investigation on Black Carbon Snow Albedo Reduction



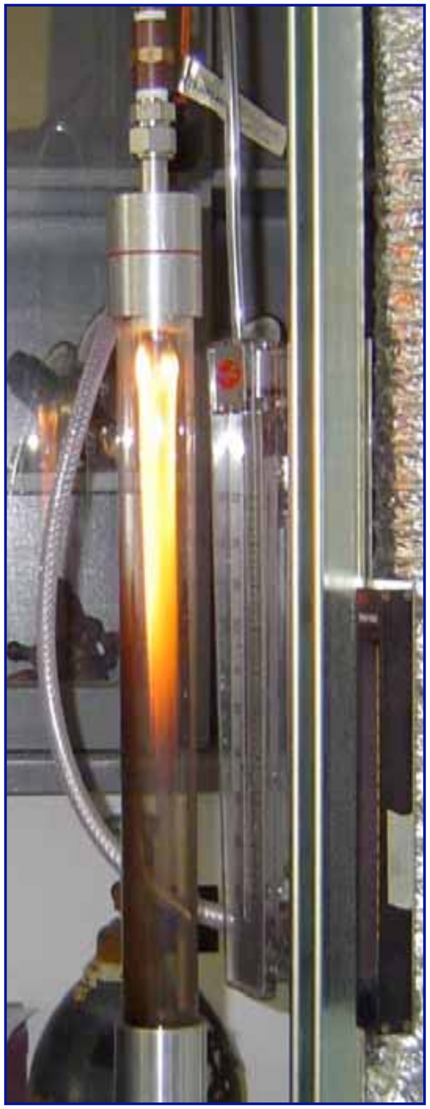
- Objective: Make sooty snow in the lab to directly measure black carbon impact on snow albedo
- Open questions include
  - ⇨ impact of snow grain size on BC induced albedo reduction (laboratory)
  - ⇨ transport of BC during melting: does BC concentrate at surface? (proposing field measurements, see poster)

Laboratory Investigation on Black Carbon Snow Albedo Reduction

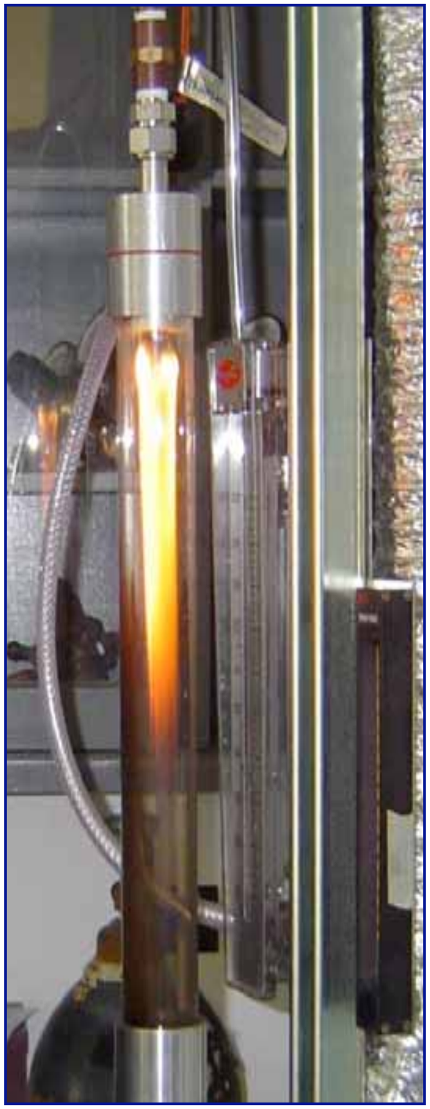
1. BC Content in Snow & Ice → 2. **Albedo Reduction** → 3. Climate Effects

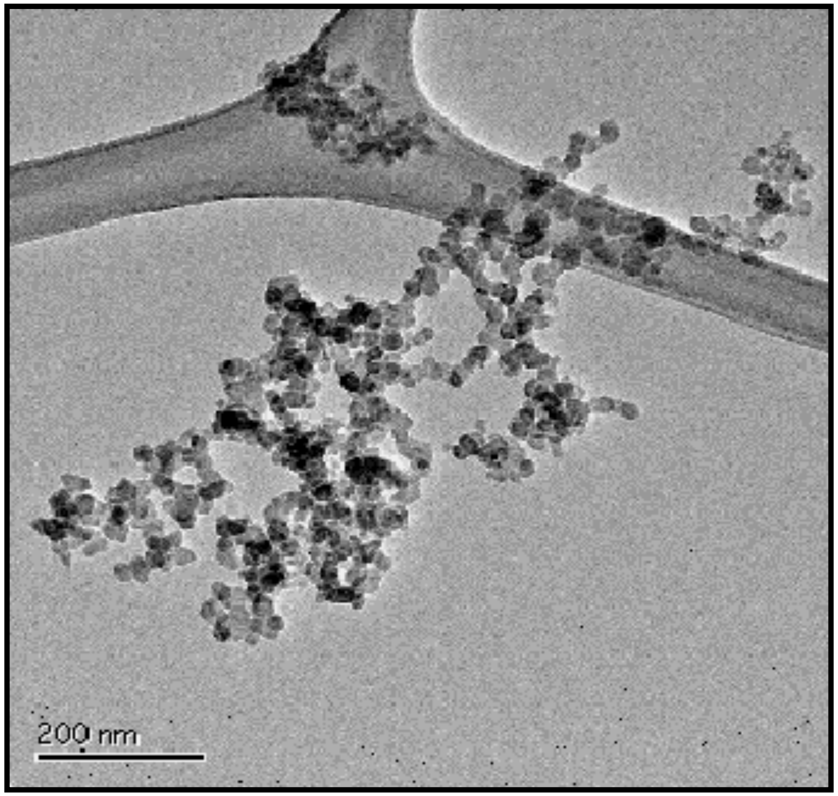
1. Make pure and sooty snow
2. Characterize snow grain size & shape
3. Measure snow albedo
4. Measure the BC concentration in snow
5. Compare with model predictions of albedo

Making Sooty Snow: Diffusion Flame

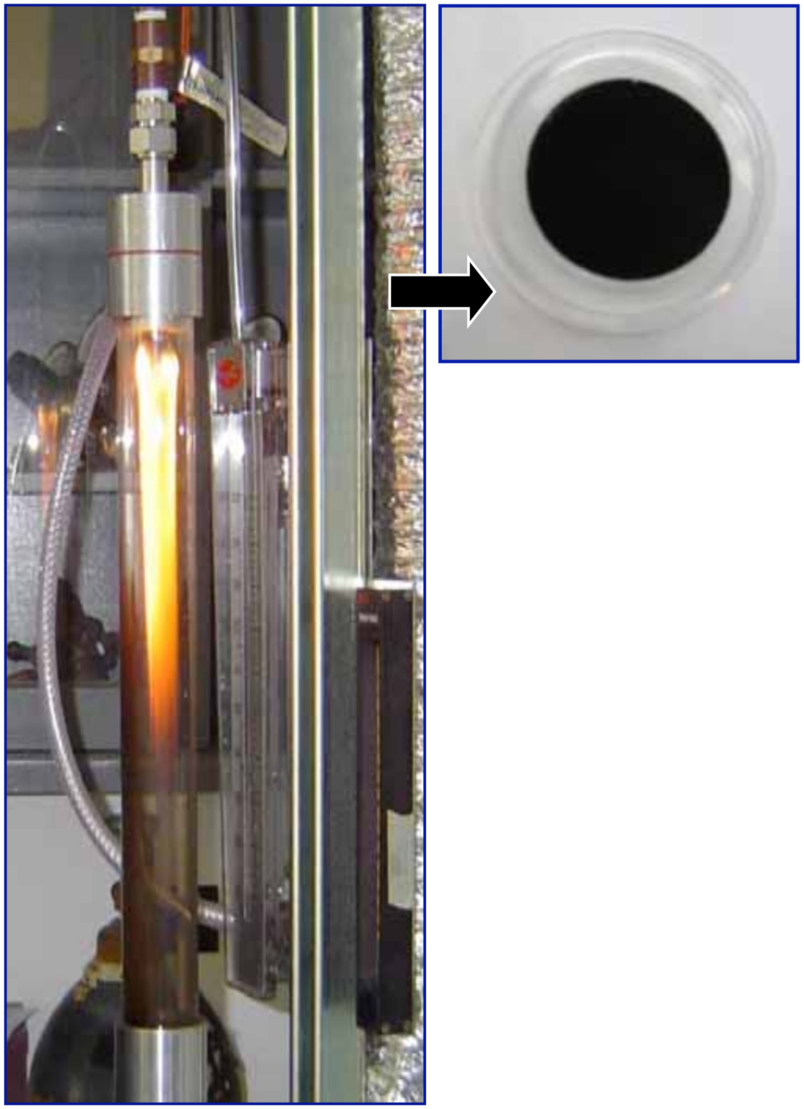


Making Sooty Snow: Soot Morphology

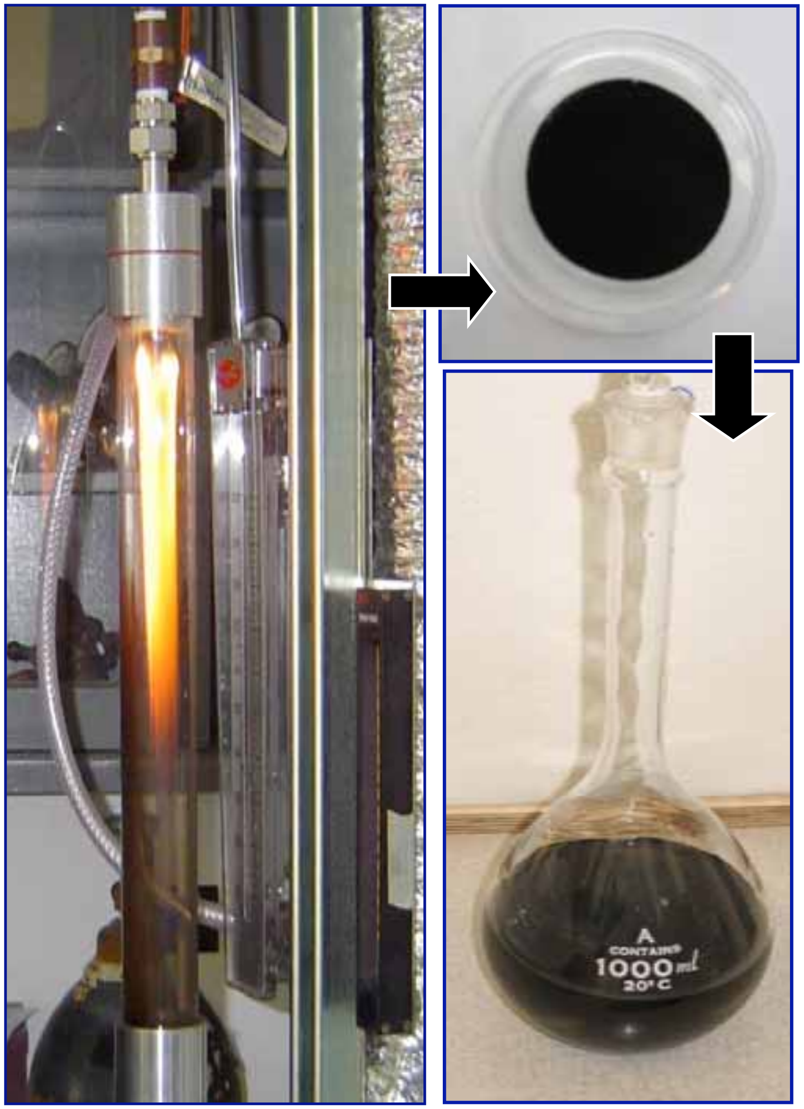




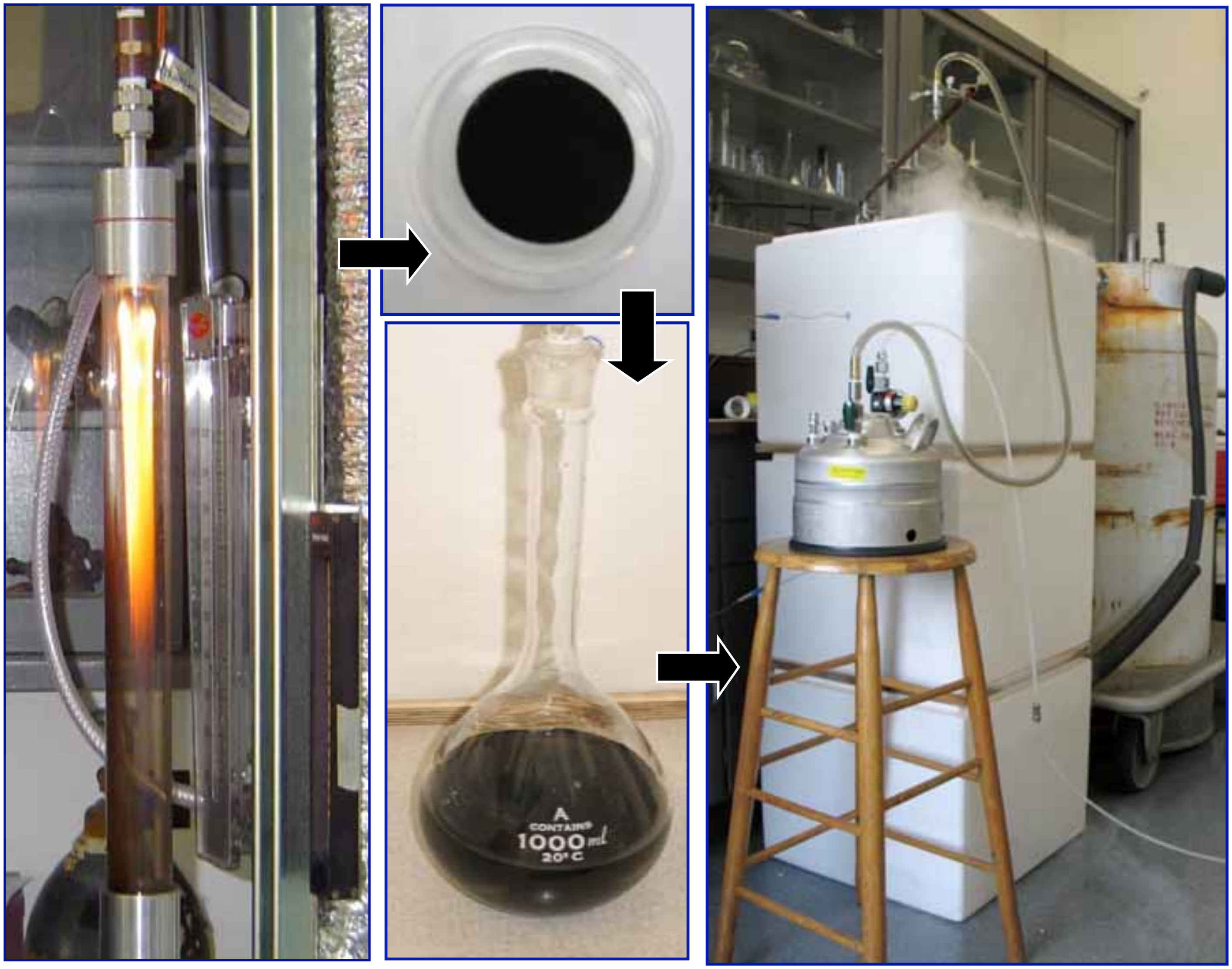
Making Sooty Snow: Collect w/ Filter



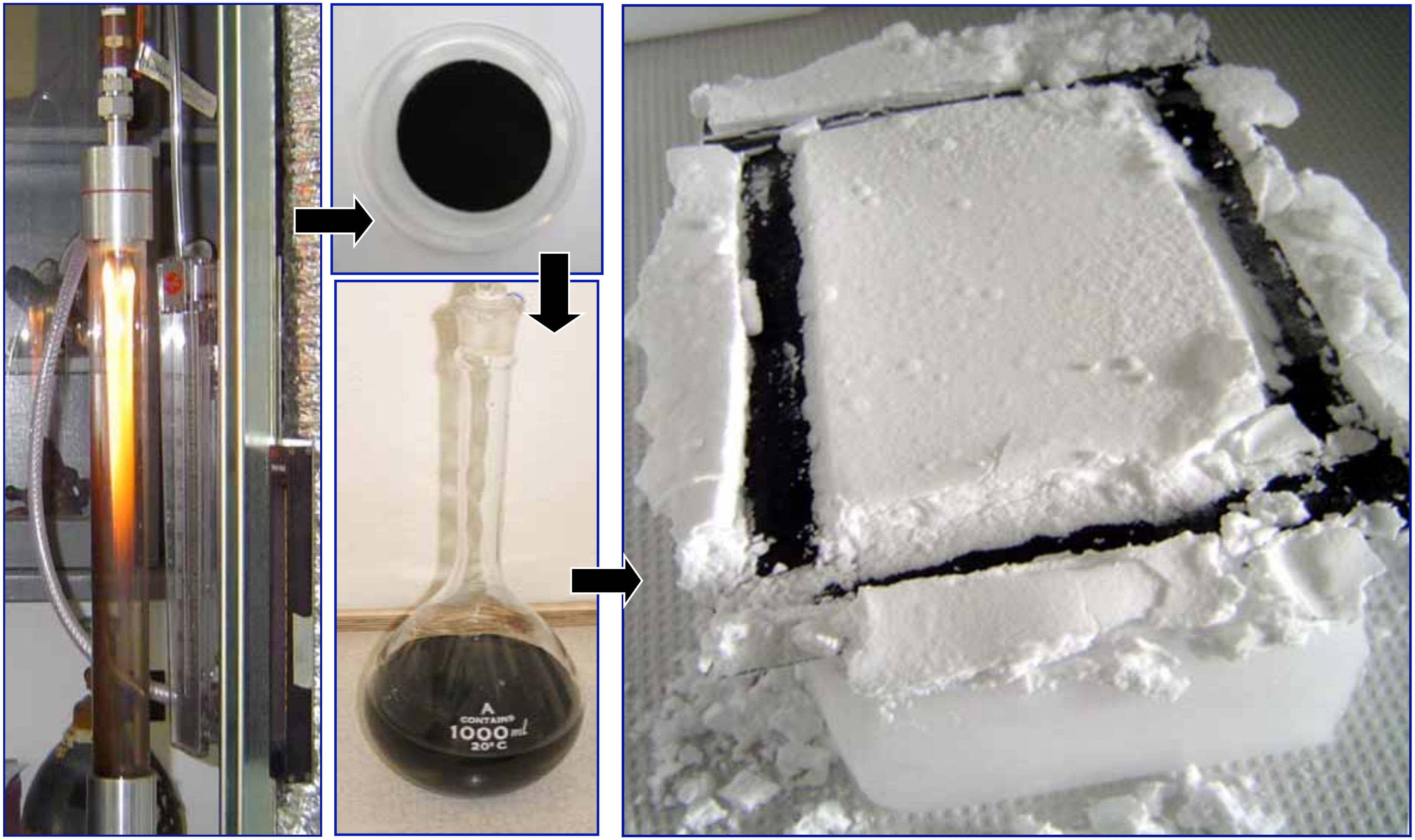
Making Sooty Snow: Make Hydrosol



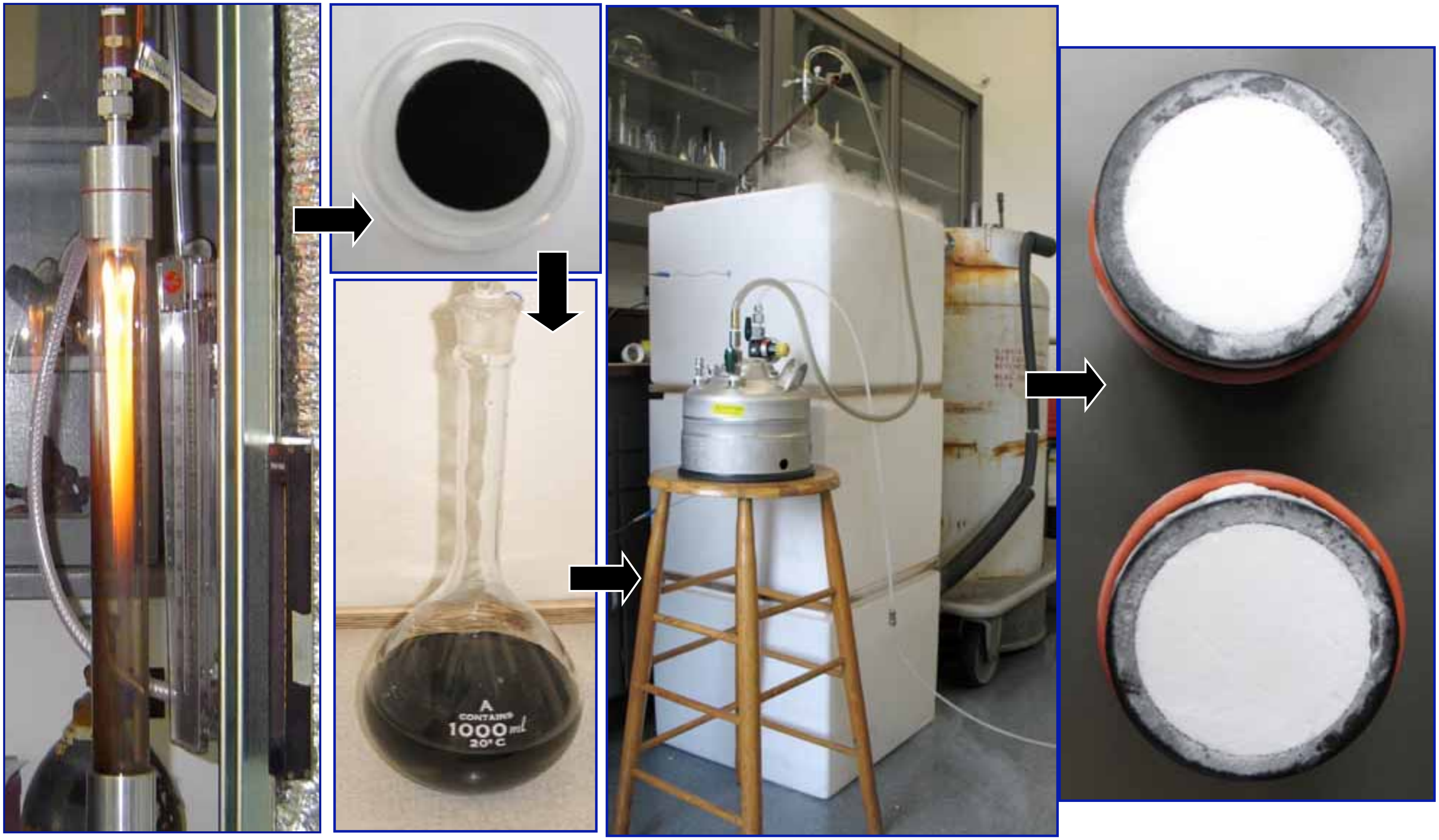
Making Sooty Snow: Spray Chamber



Making Sooty Snow: Viola!



Making Sooty Snow: Collect Samples

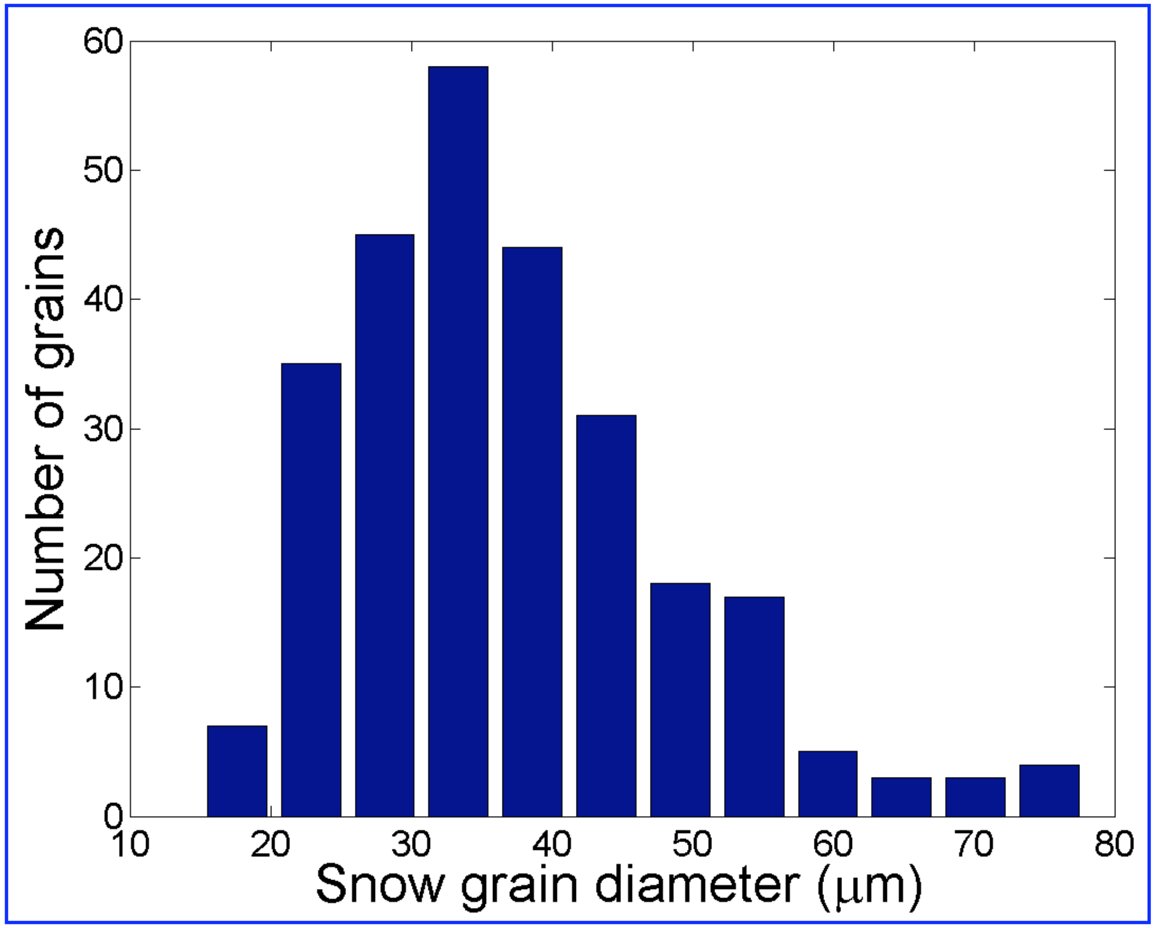


Snow Grain Size Characterization

Digital Microscope

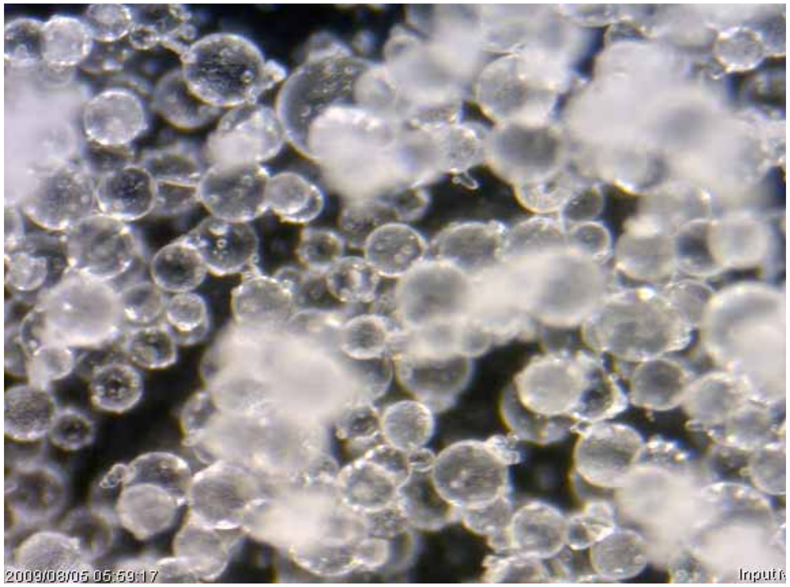
Snow Image, Magnification 512x

Snow Grain Size Characterization

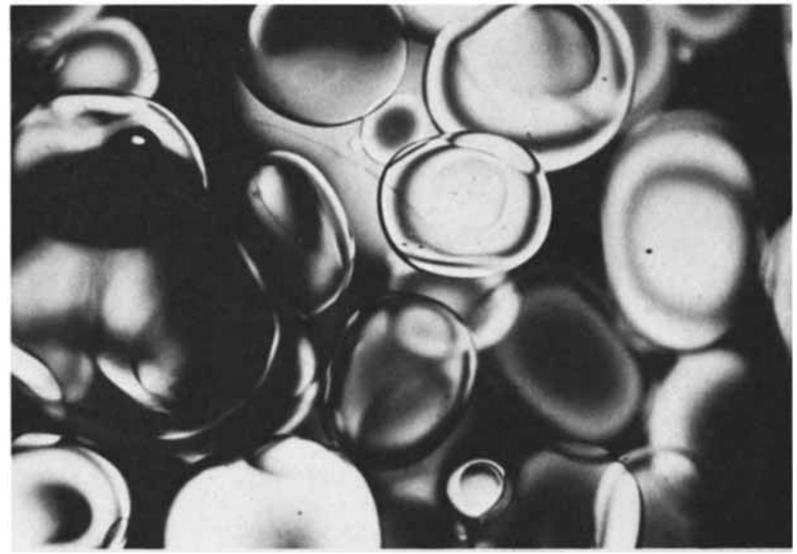


Digital Microscope	Snow Grain Size Distribution (n=271)

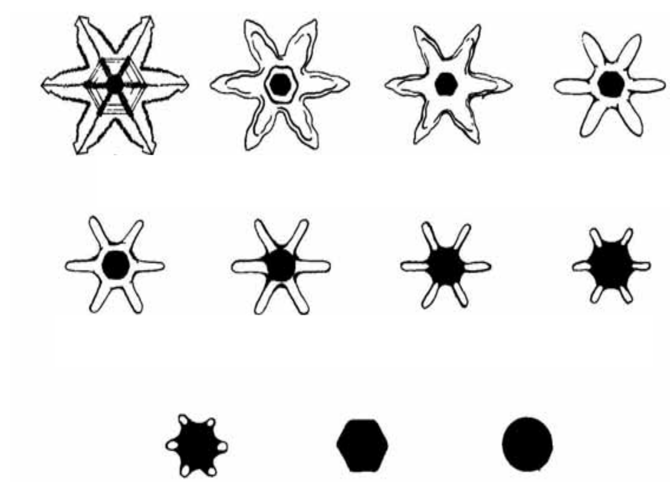
Laboratory Snow



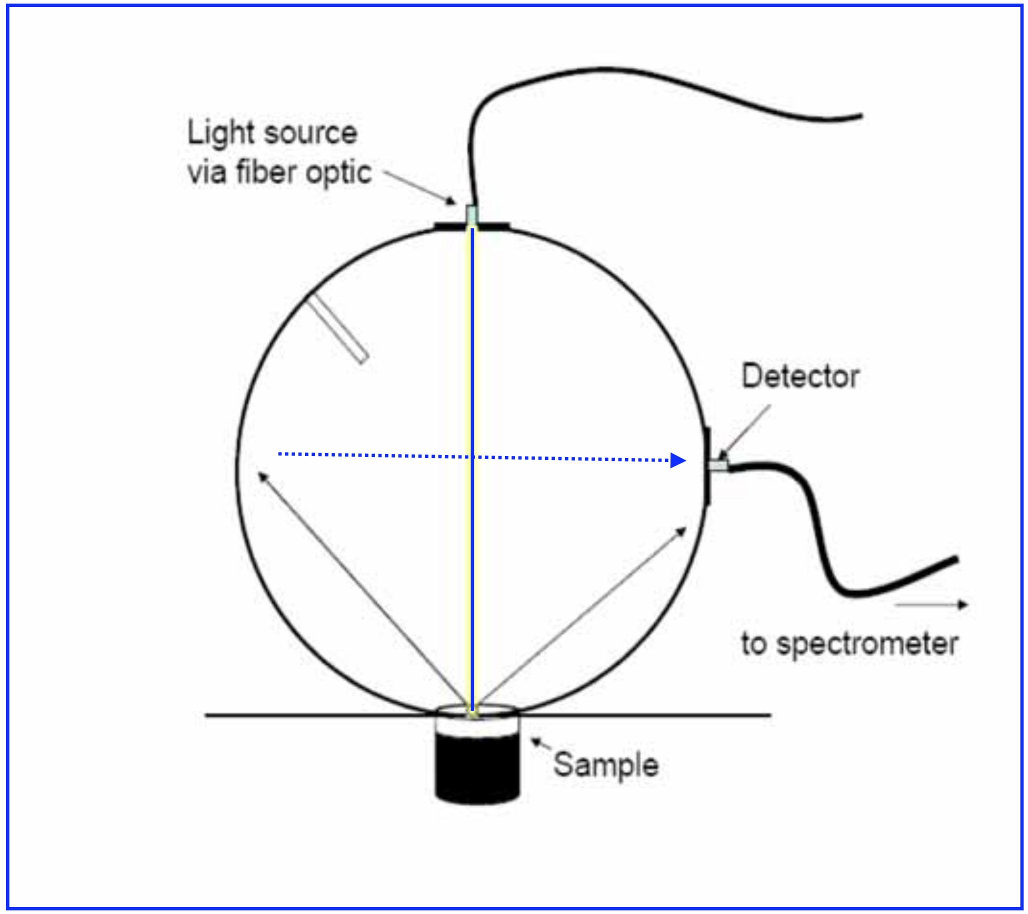
Natural Snow



Snow Metamorphism, (Colbeck, 1982)

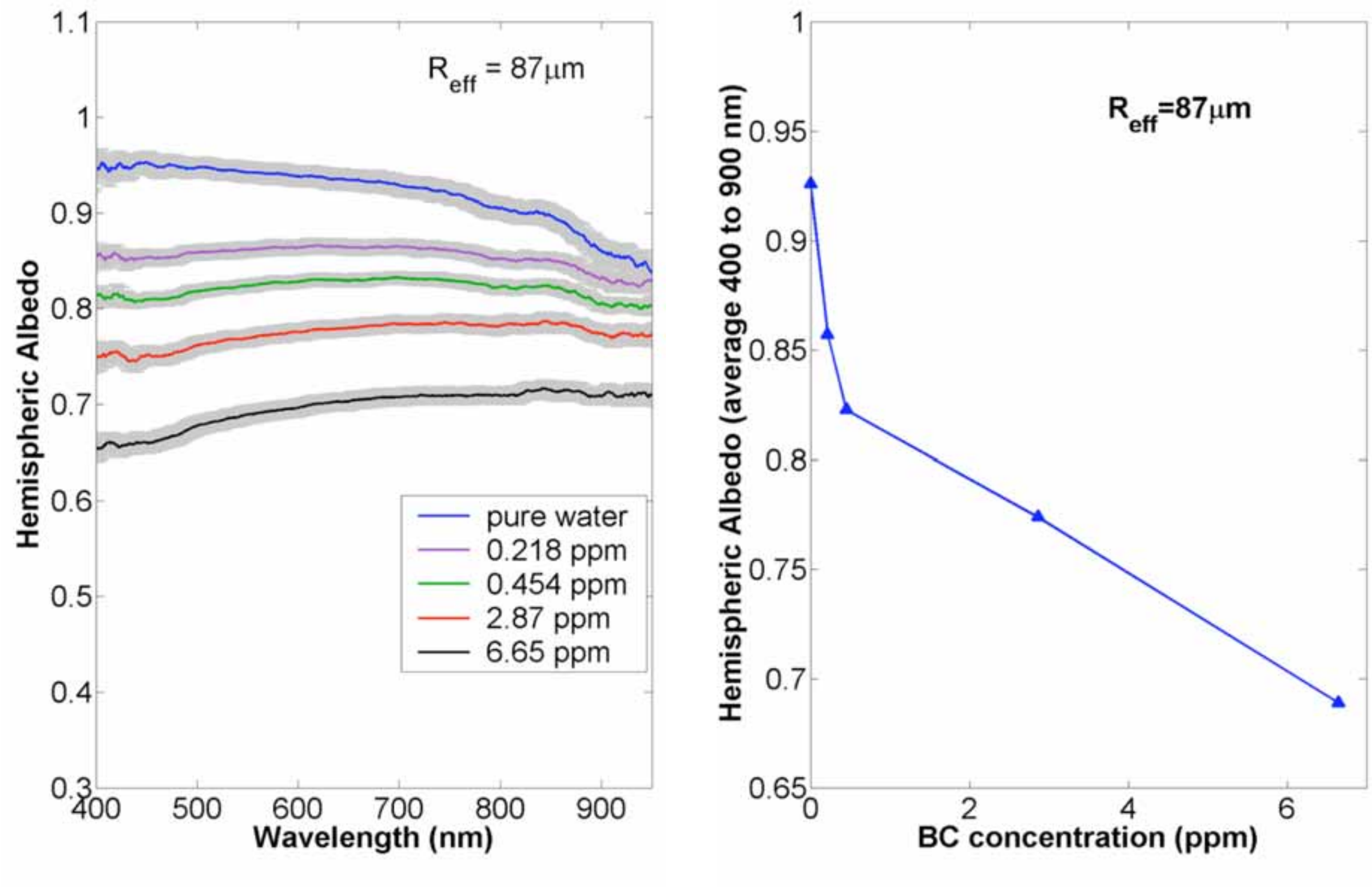


Snow Albedo Characterization

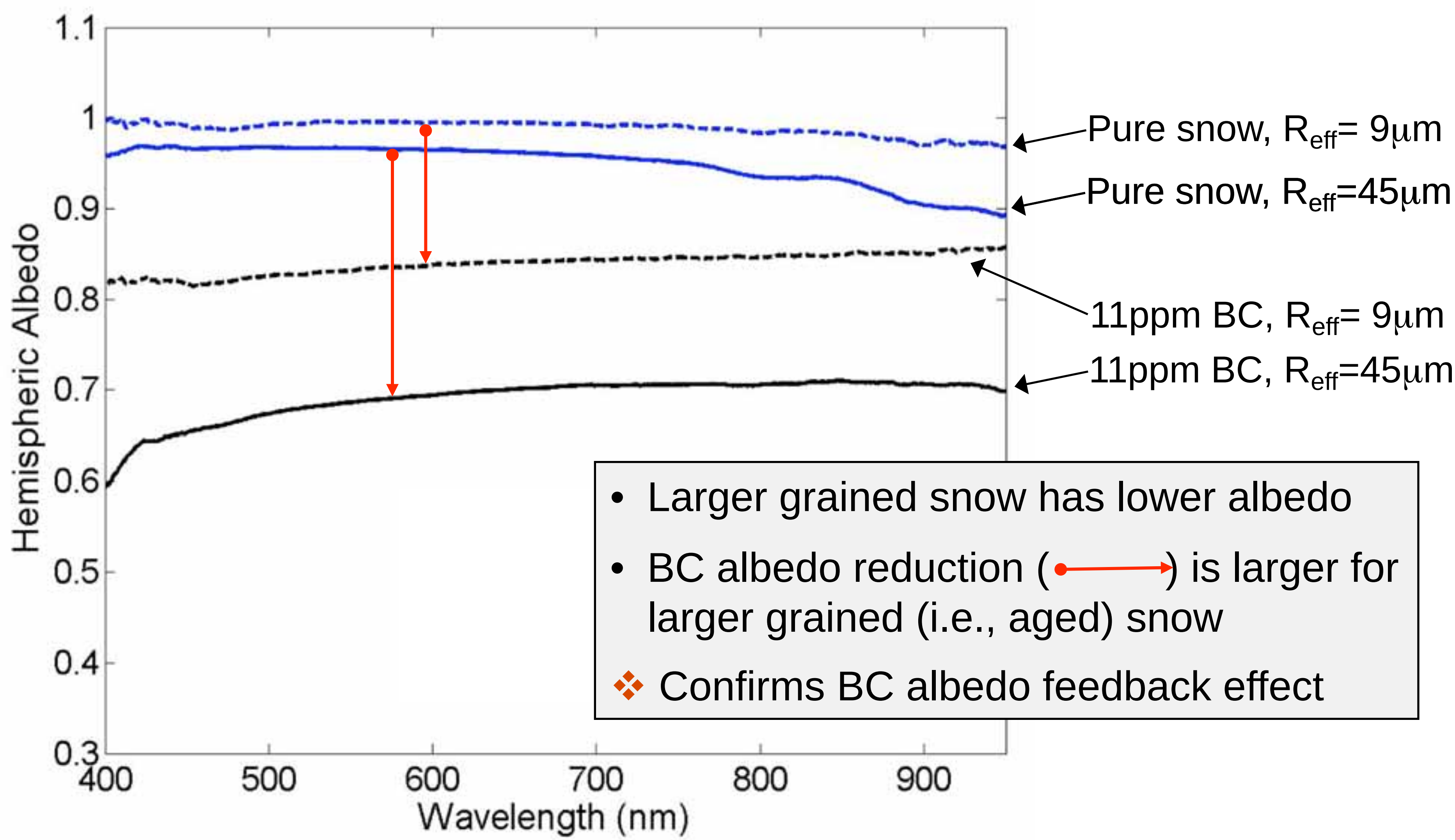


Integrating sphere collects light scattered in all directions from snow (Lambertian reflector) and delivers it to spectrometer

Measured BC Snow Albedo Reduction



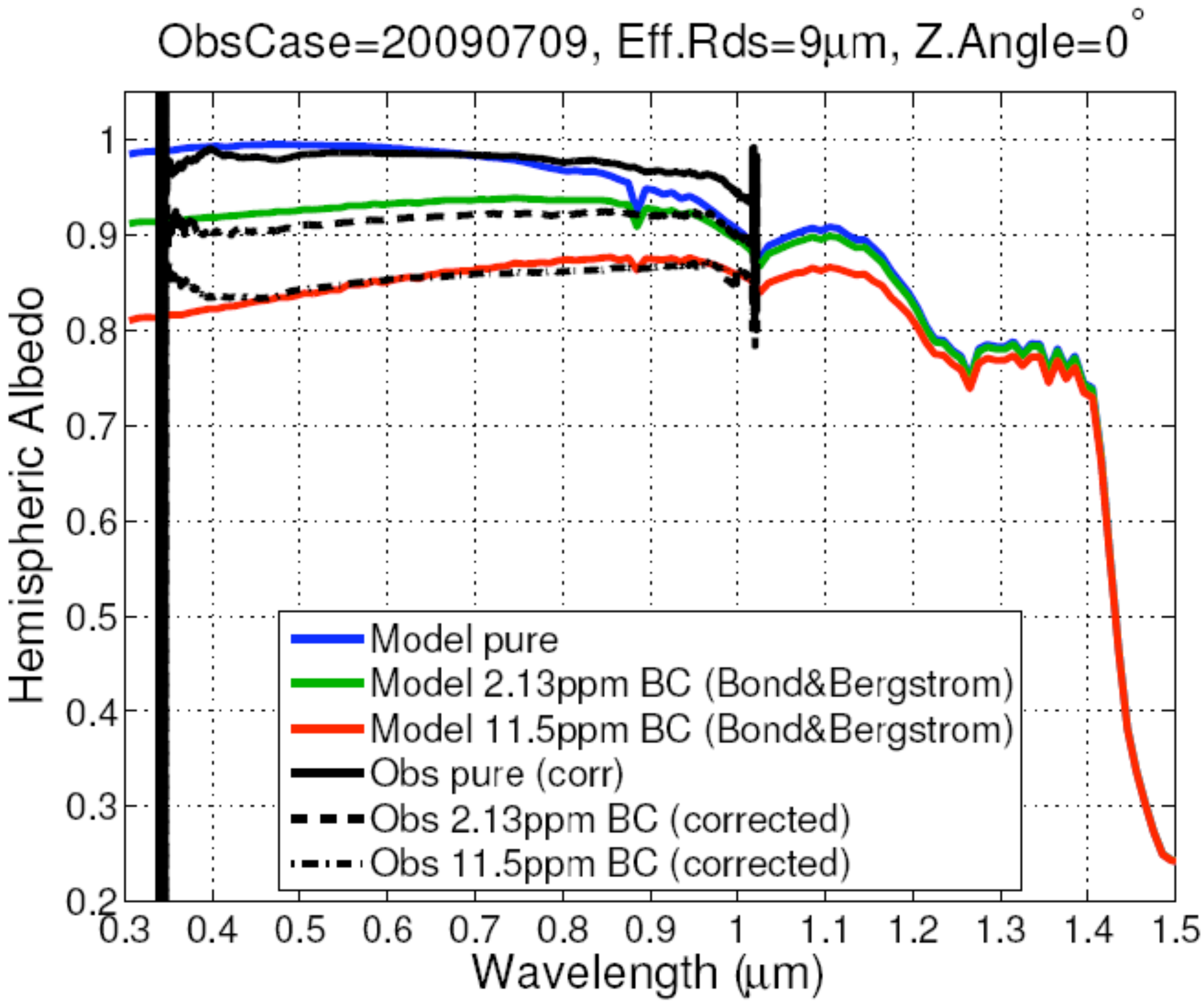
Effect of Snow Grain Size on Albedo and Black Carbon's Impact



- Larger grained snow has lower albedo
- BC albedo reduction (→) is larger for larger grained (i.e., aged) snow

❖ Confirms BC albedo feedback effect

First Comparison with SNICAR* Model



- Measured and predicted albedo agree within limits of precision
- Our measurements cover spectral region where black carbon is predicted to have an impact

(* SNICAR = Snow, Ice, and Aerosol Radiative model)

Summary and Conclusions

1. Cookstoves contribute substantially to global emissions of black carbon and dominate black carbon emissions in some regions
2. We are initiating CEC sponsored tests to quantify possible emissions changes with improved stove technology (Berkeley-Darfur Stove)
3. Aerosol transport carries black carbon from Asia to California, where snow is melting earlier than historic avg
4. We have initiated lab experiments to constrain the effect of black carbon on snow albedo and plan field measurements to evaluate black carbon transport in snow (see poster)